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Experimental investigation on laser assisted surface tempering of AISI D2 tool steel

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Abstract

This paper deals with an experimental investigation of laser tempering of AISI D2 tool steel. The Nd: YAG laser was used for the tempering. The laser was delivered through a fiber optic cable from the source to the delivery head. The laser delivery head was mounted in a lathe using a special fixture for treating the cylindrical work pieces. The effect of laser parameters such as power and spot size, and machine parameters such as surface speed and feed were studied. The microstructures of the laser tempered samples show tempered white layer and dark heat affected zones in all work pieces. The variation of micro hardness was measured from the top surface of work piece to the depth of heat affected zone and plotted.

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Keywords: AISI D2; Surface treatment; Laser assisted tempering; Nd:YAG

1. Introduction

Manufacturers around the world are constantly exploring innovative processes to process high strength material such as AISI D2 Steel which was a high-carbon, high-chromium tool steel used in high-duty cutting tools, punching tools, measuring instruments and gauges, where excellent wear resistance required. Manufacturers are also concurrently striving to meet demands on productivity, waste reduction, and sustainability. Industrial lasers have been the innovative processes for the past two decades which rapidly replaces the conventional tools in many diverse areas of manufacture, enabling increased productivity, functionality and quality.

Laser-Assisted Machining (LAM), an innovative technology in which laser was used as the heat source with its beam focused on the work piece directly in front of the cutting tool. The induced temperature was sufficiently high

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to cause reduction of hardness to the surface layer of the material. The cutting action of the tool was ductile deformation rather than brittle fracture for hard materials [1-3]. Although this process can enhance the machinability of hard materials, it has certain constraints when it comes to practical implementation, which includes physical and safety challenges associated with integrating a laser systems into a machine tool and the necessity of a relatively high power laser to induce sufficient thermal softening to achieve required material removal rates.

Laser assisted hardening was a new type of process in the surface treatment of the material. Shin et al. [5] studied the effect of laser parameters on width of the hardened areas and hardness value. Mahmoudi et al. [6] investigated in the AISI 420 martensite steel about the hardness depth, value and corrosion behavior of the specimen. Orazi et al. [7]developed a model to predict the surface hardening by the faster heat cycle of the laser beam. Due to the fast cycle the partial pearlite transformation was taken place. Effect of laser parameters on surface hardening of study was carried in two different ductile iron grades was investigated by Soriano et al. [8]. Recently, Lambiase et al. [9] developed an expert system to predict the effect of the process parameter for laser surface treatment.

It is eminent from the laser hardening literature that laser overlapping scans can cause a reduction in the material hardness in the overlap region due to a tempering effect. Laser assisted tempering, an alternative innovative method of shaping hard materials. This approach involves a two step process consisting of laser tempering of the hardened work piece surface followed by conventional machining at higher material removal rates with lower cost ceramic tools to efficiently remove the tempered material. In addition, by selecting appropriate laser scanning conditions, it is possible to control the extent of tempering in the subsurface of the hard material. This material behavior can be used effectively to increase both the material removal rates in hard materials and improve the performance of the tool or alternatively reduce tooling cost through the use of less expensive tool material.

Laser surface tempering has not yet been studied extensively. Further, it has not received wide industrial attention. Hence, it was essential to investigate the laser surface tempering process to attain controlled reduction in the subsurface hardness of hardened material. A relationship between the laser process parameters such as laser power, spot size and the variation in subsurface hardness needs to be recognized. Though hardened steel can then be case-tempered without affecting the harder bulk material, from a machining standpoint, the tempering behavior can be used to enhance the machinability of difficult-to-machine materials such as AISI D2 steel. In addition, a tempered sub surface region in the cutting zone implies higher material removal rate without significantly diminishing tool life. Hence it is essential to explore the tempered subsurface region of AISI D2 Steel, Identify the vital parameters which influences the tempering and results in higher material removal rates, and improved tooling performance with the new hybrid turning approach proposed for machining AISI D2 Steel.

This paper aims to explore the laser tempering of hard steel AISI D2 steel. Initially the experimental setup is presented followed by analysis of the tempered AISI D2 steel microstructure subjected to laser scans. The study also identifies the vital laser scanning parameters that influence the largest depth of tempered layer of AISI D2 steel.

2. Experimental details

2.1. Work piece material

High chromium AISI D2 tool steel was commonly used for many tooling applications such as stamping punches and dies, stamping or forming dies, forming, rolls, slitters, shear blades etc.The dimension size of specimen was diameter 42mm × 300mm length (Fig. 1.a). Hardness of the material was 45 HRC. Chemical composition of AISI D2 material was shown in Table 1.

Table 1.Chemical composition of AISI D2 material (Wt. %)

C	SI	Mn	P	S	Cr	Mo	Ni	V	W	Ti	Pb	Al	Cu
1.64	0.29	0.4	0.014	0.003	11.4	0.73	0.26	0.95	0.15	0.005	0.001	0.029	0.14

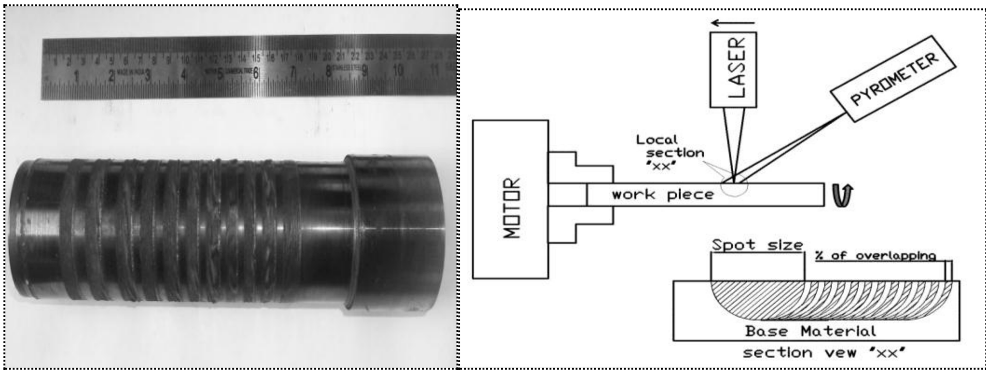

Fig.1(a) Specimen after Laser Assisted Tempering; (b) Schematic Diagram of Laser Tempering

2.2. Experimental setup

The experiments were conducted on a 2.0 HP Gedee Weiler high speed lathe, a solid state 2 kW Nd:YAG laser with continuous wave length was used.The laser head was positioned at 90° ahead of the cutting tool and the beam was delivered by a fiber optic cable through a lens. Focal lengthof 160mm was used. A Pyrometer was mounted at an angle of 45° ahead of the cutting tool to measure the surface temperature of the material. Compressed air used at the pressure of 0.5bar to protect the laser head lens from excess heat. The schematic diagram of laser assisted tempering was shown in Fig.1 (b).

2.3. Experimental design

Three set of experiments was carried to find out the optimum process parameter for the laser assisted tempering. The variable process parameters selected arelaser power (w), linear speed of workpiece (m/min) and spot size (mm). The parameters feed rate 0.025mm/rev is kept constant. In the first set of the experiments the variable factor was power and remaining parameters are constant, second set of experiments the variable factor was speed and remaining parameters are constant, and the third set of experiments the variable factor was laser spot size and remaining parameters are constant. Each set of experiments were carried out with one variable factor and three levels. Te experimental matrix is described in Table.2

Table2: Experimental Matrix

SL.No.	Ex.No.	Speed (mm/min)	Power (W)	Spot size (mm)
1 set	1	12	1000	2
	2	12	1200	2
	3	12	1400	2
2 set	4	14	1000	2
	5	16	1000	2
	6	18	1000	2
3 set	7	12	1000	3
	8	12	1000	4
	9	12	1000	5

3. Results and discussions

The experiments were carried out based on the design of experiment shown in Table.2. It investigates about the tempered hardness depth and hardness value. The result of the process parameters is shown in Table.3.

Table.3.Output Responses

Input parameters			Output responses		
Speed (m/min)	Power (W)	Spot size (mm)	Temp Depth (mm)	Temp Hardness (HRC)	HAZ (mm)
12	1000	2	0.5	32	0.5
12	1200	2	0.4	28	0.35
12	1400	2	0.45	18	0.52
14	1000	2	0.45	30	0.31
16	1000	2	0.55	32	0.32
18	1000	2	0.5	28	0.3
12	1000	3	0.35	48	0.12
12	1000	4	0.25	40	0.18
12	1000	5	0.35	43	0.16

3.1. *Microstructure*

After experimentation the specimens were sliced by using a wire EDM, it was cold mounted, polished and etched using 2% of concentrated nitric acid and 98% of the methanol. Each specimen was hold for 9 s in etchant. Microstructures were taken in the optical microscope in 100× magnified lens.

In the first set of DOE, power was varied and the effects of the varied power influence were observed from Fig.2.(a). The tempered depth was about 40% and heat affected zone was around 60%. The reason for large heat affected zone was due to high power.

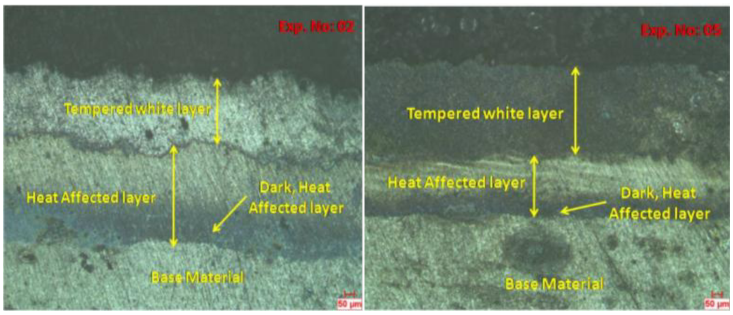

Fig.2.(a).Microstructure of Exp.2; (b). Microstructure of Exp.5

In the second set of DOE, speed was varied and the effects of the varied speed influence were observed from Fig.2.(b). The tempered depth was about 60% and heat affected zone was around 40%. The reason for large tempered layer was due to optimum power and low speed.

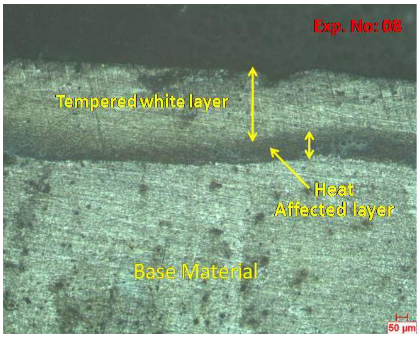

Fig.3.Microstructure of Exp.8

In the third set of DOE, laser spot size was varied and the effects of the varied spot size influence were observed from Fig.3. The tempered depth was about 70% and heat affected zone was around 30%. The reason for large tempered layer was due to large spot size.

3.2. Analysis of the Output Responses

The output response was analyzed using MINITAB 16 Software and the graphs are plotted based on the results of the design of experiments performed.

First set of experiments were carried out in order to find out the influence of the laser power for the tempering depth and the tempering hardness. Parameters of feed rate, speed, and laser spot size are kept constant, only the power was varied from 1000W to 1400W.When the power was increased tempering hardness was goes on decreasing, which was inversely proportional to the tempering hardness. The maximum tempering hardnessof 33HRC was achievedin the 1000W and the minimum tempering hardnessof 17 HRC was achieved in the 1400W.

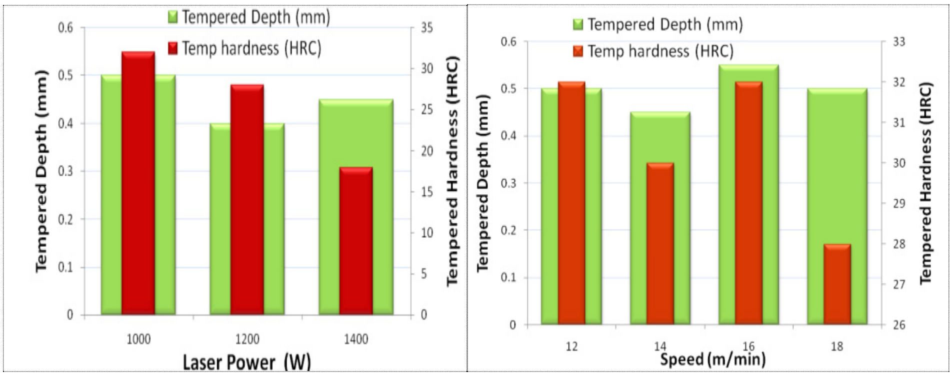

Fig.4.(a). Responses based on Laser Power Varied; (b).Responses based on speed

The results show that power was influencing the temperedhardness. But the optimum value of tempering depth and the tempering hardness of 0.5mm & 32HRC was achieved in the 1400W (Exp 3). Fig.4.(a) depicts the tempered depth and tempered hardness at different laser powers.

Second set of experiments were carried out in order to find out the influence of the laser scanning speed for the tempering depth and the tempering hardness.Parameters of feed rate, power, and laser spot size are kept constant, only the laser scanning speed of was varied from 12 m/min to 18 m/min.The variation of the scanning speed was not influencing in the tempering depth almost the average depth of all the experiments was 0.5mm and what was the value achieved in the first set of experiments of 1000W laser power. This was achieved due to the constant of laser power(1000W) used for this set of experiments. But there is the variation of the tempering hardness due to the change of the scanning speed. The maximum hardness value of 32HRC was achieved in scanning speed of 12m/min(exp1) and the minimum hardness of 28HRC was achieved in scanning speed of 18m/min(exp 6).But the optimum value of tempering depth and the tempering hardness of 0.45mm & 30HRC was achieved in the 14m/min(Exp 4).The results shows that the speed does not influence on tempered depth only influencing on the tempering hardness. Fig.4(b)depicts the tempered depth and tempered hardness at different speeds.

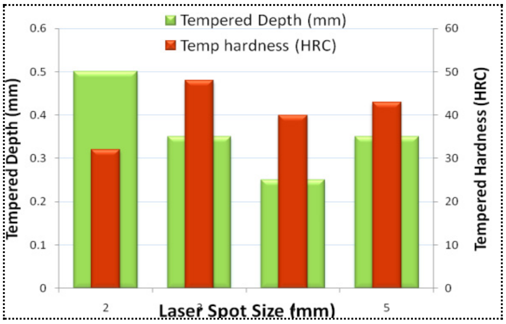

Fig.5.Responses based on laser spot size

Third set of experiments were carried out in order to find out the influence of the laser spot size for the tempering depth and the tempering hardness.Parameters of feed rate, power, and laser scanning speed are kept constant, only the laser spot size was varied from 2 to 5 mm.When the laser spot size was increased tempering depth was goes on decreasing up to certain level after that the tempering depth and the tempering hardness also increased due to larger spot size of laser. The maximum tempering depth of 0.5mm was achieved in the 2mm spot size and the minimum tempering depth of 0.3mm was achieved in the 4mm spot size.But the optimum value of tempering depth and the tempering hardness of 0.5mm & 30HRC was achieved in the 2mm laser spot size (Exp 1).The results show that the laser spot size was influencing on both the tempered depth and the tempering hardness. Fig.5.depicts the responses of the tempered depth and tempered hardness for varied laser spot size.

4. Conclusions

In this paper the effect of laser parameters such as laser power, speed of work piece and spot size on tempering depth and hardness value of D2 steel. The following conclusions were obtained from the experimental results.

a. The tempered hardness reduces as the laser power increases. But influence of power was not significant for the tempered depth.
b. The tempered depth increases as the laser spot size decreases. But influence of laser spot size was not significant for the tempered hardness.
c. The laser scanning speed does not have significant influence on tempered hardness and tempering depth.
d. For the first set of experiments the optimum value for the tempered depth and tempered hardness was 1400W laser power.
e. For the third set of experiments the optimum value for the tempered depth and tempered hardness was 14m/min laser scanning speed.
f. For the third set of experiments the optimum value for the tempered depth and tempered hardness was 2mm laser spot size.

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